DIFFERENTIAL COVERING AND COATING METHODS

PRIORITY CLAIM

This patent application is a continuation in part of and claims the benefit of priority under 35 U.S.C. § 120 to co-pending U.S. Nonprovisional Application Serial No. 10/288,615, filed November 5, 2002, which is incorporated in its entirety by this reference.

FIELD OF INVENTION

The present invention relates generally to methods of covering and/or coating medical devices and more particularly to methods of manipulating the compliance of the cover to modify fluid mechanics on the interior of the medical device and the friction points on the exterior thereof.

BACKGROUND OF THE INVENTION

Stents are devices that are inserted into a vessel or passage to keep the lumen open and prevent closure due to a stricture, external compression, or internal obstruction. In particular, stents are commonly used to keep blood vessels open in the coronary arteries and they are frequently inserted into the ureters to maintain drainage from the kidneys, the bile duct for pancreatic cancer or cholangiocarcinoma or the esophagus for strictures or cancer. Vascular as well as not vascular stenting has evolved significantly; unfortunately there remain significant limitations with respect to the technology for producing stents suitable to various portions of a patient's anatomy.

Historically, in order to provide a stent with varying characteristics, the stent had to be manufactured from multiple materials, at least one for each characteristic desired. As a result, many of these stents are woven from two or more metals having differing shape-memories for example. Unfortunately, braided stents are vulnerable to premature obsolescence. Moreover, providing multiple material types in a single stent may lead to inconsistent characteristics along the surface area of the stent. This is particularly undesirable when the stent is to be placed in vascular or nonvascular lumens that have been occluded for one reason or another. The stent needs to be stiffer in some regions while more flexible in others.

Additionally, medical device companies have identified the need to cover stents at least partially to prevent the epithelialization of the scaffolding. Most covered stents however have an elastomeric cover that is subject to bunching particularly about stenotic tissue. This can lead to additional tissue granulation. Additionally, the stents are dip coated which can lead to uneven coating as well as inconsistency in stent performance from batch to batch.

Additionally the ends of the stent tend to be exposed in order to encourage granulation tissue formation, which helps to anchor the stent in place. With metal stents, the direct metal to tissue contact accelerates tissue granulation and galvanic current generation is also an undesirable byproduct. Such direct current can have indirect effects on tissue granulation and direct effects on fluid flow dynamics.

Moreover, since many medical device companies have chosen to use poorly adapted cardiovascular stents for Pulmonary, GI and Peripheral Vascular indications, many of the anatomical differences in the lumens are not accounted for in stent design. For example, the

pulsation of the cardiovascular lumen and the concomitant radial force requirements of a cardiovascular stent differ substantially from that of a tightly constricted lumen such as the trachea during repeated coughing. When a stent developed for the former is indicated for the latter, the stent tends to fail under the extreme conditions and lose its elasticity and therefore its ability of ensure airway patency. Non-vascular lumens also tend to have ciliated epithelia so as to facilitate clearance of fluids and particulates. As a general principal, coated stents were not specifically designed for ciliated lumen in that the external coating damages the cilia and prevents the body's natural clearing function. Moreover, the coating itself is usually made of a predominately hydrophilic polymer, which can lead to mucous formation and/or fluid stagnation. Stagnation of fluids or material passing through the lumen can lead to additional complications such as in stent restenosis or bacterial infections.

Therefore, there remains an existing need for a therapeutic stent that can have varying characteristics along its surface area while being stamped, not braded, from a single base material. Moreover, there is a need for such a therapeutic stent where the relative hardness, softness, flexibility, stiffness and radial force can be modified as a function of geometric considerations rather than material considerations. In particular, there is a need for a stent that is divided into zones so as to allow the stent to have predetermined characteristics in one zone and could conceivably have drastically different characteristics in an adjacent zone so as to allow for stents that can be tailored to anatomical lumens in general and the particular lumen topography of a specific patient in particular. An additional need exists for a method of differentially modifying the location, compliance, and density of the cover to achieve desired

behavior. In particular, there is a need for a covered stent that is preferably covered internally such that the outer scaffolding surface of the stent is raised from the outer surface of the coating. To this end, cilia function is only partially limited and mucociliary clearance is not significantly affected. A need also remains for a coating that itself has anti-adherent properties or is complexed with an anti-adherent such that bacteria, fungi or other microbials cannot colonize the cover in particular and the stent generally. There also remains a need for a cover for the proximal and distal ends of the stent that prevent epithelialization and granulation tissue formation while achieving the benefits of traditional uncovered stents.

SUMMARY OF EXEMPLARY EMBODIMENTS

It is a principal purpose of the present invention to provide a stent, in accordance with an exemplary embodiment of the present invention, which combines many of the excellent characteristics of both silicone and metal stents while eliminating the undesirable ones. In particular, it is an objective of a preferred embodiment in accordance with the present invention to provide a stent that is easily installed, yet in alternative embodiments, removable. Moreover the stent in accordance with this embodiment of the present invention would not cause material infections and may be capable of reducing infection. Therefore, a principal objective of a preferred embodiment in accordance with the present invention is to provide a prosthesis that is suitable for both permanent and temporary use while being easy to insert, reposition and remove.

A principal objective of a preferred embodiment of the present invention is to provide a stent that may be stamped from preferably a single material that is capable of maintaining its axial working length

when radially compressed. To this end, the stent does not have a seam that could aggravate luminal tissue. In particular, a stent in accordance with the present invention is formed using a tool that molds the stents outer contour as well as its interstices.

It is yet another objective of an exemplary embodiment of the present invention to provide a stent that can be indicated for the treatment of benign and malignant disease and improve the way clinicians treat malignant obstructions.

Still another objective of the present invention is to provide a stent and method for installing the stent that is economical and suitable for routine purposes. Moreover, the stent will have minimal migration, cause minimal tissue granulation, will not foreshorten after deployment and mucociliary clearance will not be problematic.

Yet another objective of an exemplary embodiment in accordance with the present invention is to provide a prosthesis that will have superior internal to external diameter ratio, superior radial force with dynamic expansion, while being suitable for use in pediatric and adult patients with malignant and benign disease.

A principal objective of an exemplary stent in accordance with the present invention is to provide a family of stents where the relative hardness/softness of regions of the stent can differ from other regions of the stent to provide additional patient comfort and resistance to radial forces.

An additional objective in accordance with an exemplary embodiment is to provide a family of stents with novel interstice configurations that facilitate flexibility, durability and/or proper installation.

Still another objective of a preferred embodiment of the present invention is to provide a self-expanding stent having the

above benefits that also defines a plurality of apertures at the termini of the stent or along the scaffolding there between for, *inter alia*, removal of the stent. In the furtherance of this and other objective, suture may be treaded through one or more of these apertures to facilitate purse string like removal of the device.

An additional objective in accordance with a preferred embodiment of the present invention is to provide a prosthesis that minimizes cilia destruction at the site of implantation. In the furtherance of this and other objectives, the preferred prosthesis is coated internally with a polyurethane such that the surfaces of the struts that come into contact with the lumen of the patient are elevated above the surface of the coating such that the cilia can move to allow for free fluid action of ciliated epithelium.

Still another objective in accordance with the present invention is to provide a cover and method for applying the cover to a stent. The cover may be applied such that the cover is at various levels of compliance with respect to the stent struts. To this end, it provides an opportunity to manipulate flow mechanics for the inner diameter of the stent as well as the friction points of the outer diameter of the stent.

Yet another objective in accordance with the present invention is to provide covering about the distal end, the proximal end or combination so as to retain the benefits of an uncovered stent while retaining the ability to remove the stent. Moreover, the end only and full stent covering may be provided in addition to the coating to eliminate galvanic current.

Further objectives, features and advantages of the invention will be apparent from the following detailed description taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 shows a perspective view of the cross-section of select struts of an exemplary stent with a covering applied to the internal diameter so as to cause the cover to conform to the stent struts.

FIG. 2 shows an alternative perspective view of the select stent strut cross-section of FIG. 1 where the cover is not compliant with the stent struts.

FIG. 3 shows an enlarged perspective view of a stent viewed from one end through the lumen thereof showing the compliant cover of FIG. 1.

FIG. 4 shows an alternative end-to-end perspective view of the stent where the cover is super-compliant in certain regions of the stent such that the cover extends through the interstices toward the outer surface of the stent.

FIG. 5 shows an enlarged perspective view of the struts where the cover does not conform to the geometry of the struts.

DETAILED DESCRIPTION OF AN EMBODIMENT

A preferred embodiment of the stent, in accordance with the present invention, provides a stent that prevents epithelialization of the stent and is not subject to premature elongation and foreshortening but is capable of engaging the desired implantation location. The stent also retains its axial length while undergoing radial compression.

The stent is preferably formed from a composite material selected from the group consisting essentially of Ni, C, Co, Cu, Cr, H, Fe, Nb, O, Ti and combinations thereof. The composite material is generally formed into a compressed tube from which the stent is etched and is formed on a suitable shaping device to give the stent

the desired external geometry. Both the synthetic collar techniques and in vitro valuation techniques show the remarkable ability of stents in accordance with the present invention to convert acting force into deformation work absorbed by the angled structure, which prevents excessive scaffolding stress and premature material fatigue and accelerated obsolescence.

Though one skilled in the stent engineering art, once apprised of the present application, would be able to manufacture a stent consistent with the present invention by other methods, a preferred method of manufacturing such stents follows. As stated above a composite material is selected and a blank is formed there from. The blank is preferably laser etched and the etch work is generally verified for accuracy using visual recording microscopy. Dimensional measurements are taken to ensure strut thickness, segment angles, zone placement, etc. Moreover, the stent is preferably formed on a shaping tool that has substantially the desired contour of the external stent dimensions.

In the event the stent is to be shaped to the dimensions of a particular lumen, optical photography and/or optical videography of the target lumen may be conducted prior to stent formation. The geometry of corresponding zones and connector regions of the stent then can be etched and formed in accordance with the requirements of that target lumen. For example, if the stent were designed for the trachea, which has a substantially D shaped lumen and additionally the middle zones needed to be softer than the end zones, the stent could be designed to those specifications. Stent angles may be modified to provide different characteristics to different zones of the stent. In particular, if the topography of the trachea of a particular patient is captured optically and the appropriate dimension

provided, a patient specific prosthesis could be engineered. These techniques can be adapted to other non-vascular lumen but is very well suited for vascular applications where patient specific topography is a function of a variety of factors such as genetics, lifestyle, etc.

It should be pointed out that unlike the use of differing shape memory materials to change regions of a stent, stents in accordance with the present invention can take on an infinite number of characteristic combinations as zones and segments within a zone can be modified by changing angles, segment lengths and segment thicknesses during the etching and forming stages of stent engineering or during post formation processing and polishing steps. Moreover, by modifying the geometry of the connectors between zones, additional functionality may be achieved.

Exemplary stents in accordance with the present invention are shown in FIGS. 1-3 showing the preferred interstice geometry. Not shown are a wide variety of interstice geometries that are also acceptable alternatives to the preferred, namely, U, V, W, Z, S and X geometries to name a few.

The stent also is formed of memory metal and preferably has unique geometrical interstices that are laser etched therein. However, other conventional ways of forming interstices in unitary stents, though not equivalent are contemplated, may be employed and would be within the skill set of one in the art.

It cannot be overemphasized, however, that this does not mean the knowledge that changes in the geometry of interstices affect stent functionality is currently known in the art. To the contrary, the present inventors discovered the interrelation between interstice geometry, width, length and relative resistance to torsional stress and

radial force. In fact, it can be said that the stent has circumferential bands extending perpendicularly with respect to the luminal device's longitudinal axis. These bands are referred to generally as zones. A connector connects these bands to one another; the connector is an additional means for adjusting stent functionality. In particular, the connector defines a substantially U shaped member, but could define other geometries such as U, V, W, Z, S and X to name a few. Also a plurality of eyelets that allow a physician to purse string the stent with suture to facilitate removability. The eyelets are preferably between about 200μm and 300μm, however, the eyelets may be smaller or larger to accommodate the need of the target site. The preferred eyelet size is about 350μm as the preferred suture type is 4-0. The medical appliance may be pre-threaded with suture or the user may provide the suture after implantation.

An exemplary stent in accordance with the present invention with relatively great torsionality and radial flexibility would be rated soft. An exemplary soft rated stent comprises distance between U shaped connectors of about 4.5 μm in the compressed state (i.e., contracted in the 3mm tube subject to laser etching). Moreover, the length of the crossing member is preferably about 1.0 μm. The lengths of the leg members are preferably about 1.5 μ m long. Additionally the leg members may further comprise feet that attached to the remainder of the stent scaffolding. The feet can be adjusted from a standard length of about 0.25 μm to further adjust the characteristics of the stent. There is additionally a substantially rectangular member incorporated in the U shaped connector with similar capacity for variability. The variability factors and results of modifying the

dimensions of the substantially rectangular members are similar to those evinced by leg length dimensional modifications.

By way of example, but not to be construed in any way as limiting, the softness index or relative flexibility can be increase by increasing the various lengths discussed above. For example, by increasing the length of the legs and crossing members of the U shaped connector, flexibility increases. However, with respect to the distance between U shaped members and distance between interstices in a preferred stent embodiment, there is an inverse correlation between length and softness. This relative softness/hardness indexing as a corollary of interstice dimensions is a novel aspect of preferred embodiment of the present invention. As a practical rule of thumb, longer leg lengths coupled with acute angles provide for greater flexibility. Conversely, shorter leg lengths and more obtuse angles provide more rigidity. By way of non-limiting example, a U shaped connector with short legs deviating from the crossing member at angles greater than 90°, will be extremely rigid and resistant to torsional strain as compared to a U shaped connector with longer legs diverging from the crossing member at angles less than 90°.

In addition to the length and spacing differences, the interstices themselves may define various shapes that by their very nature afford novel functionality to the stent. The changes of functionality, however, are more a function of the dimensional differences of the various shapes rather than a function of the shapes themselves. Therefore, it is important to keep in mind that the dimensional differences discussed in the previous paragraph are determinative of the functionality accorded the stent by the varying interstice geometries. It is for this reason that one of ordinary skill in the art, after

being apprised of the present invention, would be able to conceive of a number of interstice geometries to satisfy certain functionality criteria by keeping certain dimensional parameters constant.

FIGS. 1-3 also show the coating provided in select embodiments in accordance with the present invention. The coating preferably comprises a stable polymeric material such as polyurethane that can be deposited on a stent to form a thin film. The film preferably forms layers when annealed to the stent such that the hydrophobic moieties within the polymer are predominately oriented outward and the hydrophilic moieties are predominately oriented inward. It should be noted that depending on the characteristics desired by the user, the relative hydroaffinity may be altered. For example, in the event the implant was placed with the intention of collecting mucous in the respiratory system, the coating would more suitably have a predominately hydrophilic outer surface. Moreover, by manipulating the hydroaffinity of the coating, the physiochemical parameters such as surface-free energy, charge density provide a substantial barrier to biofilm formation in general and ligand-binding events mediated by microbial adhesions and extracellular polymers. However, additional anti-adherents know in the art may be applied to provide lubricity as well as an additional barrier for microbials. For example, a preferred coating in accordance with the present invention would be hydrophilic and hydroscope to ensure the surface would always be wet which prevents mucostasis as well as microbial adherence.

Regardless of desired coating surface characteristics, preferred stents in accordance with the present invention are covered from the interior of the stent lumen such that the stent scaffolding. The cover may be strategically applied to either form a strut compliant membrane, a non-compliant membrane within the internal diameter

of the stent or incrementally in between. One of the principal functions of the variable covering method is to enhance friction points on the exterior of the stent and/or control flow dynamics through the interior lumen of the stent.

Making specific reference to FIGS. 1 and 3, the stent struts 100 are shown with the interior lumen surface 120 facing upward. When covering the stent struts 100 from the interior surface 140, a compliant cover forms angles between the struts 100 that can cause fluid retention. If this is a desirable characteristic based on the target lumen of the stent, such covering can be achieved by using a compliant heating mechanism when coupling the cover 200 to the struts. Alternatively, as shown in FIGS. 2 and 5, if a relatively smooth interior diameter is desired, the cover 200 would be applied to the struts 100 with a non-compliant device so as to prevent the cover 200 from conforming to the contours of the stent struts 100.

With respect to FIG. 4, there may be instances where the cover 200 needs to be super compliant such that the cover 200, though applied to the inner surface 120 of the stent, the cover extends through the interstices to the outer surface 140. By modifying the cover compliance between these extremes, it is possible to optimize the degree of friction and flow based on desired design metrics.

The stent is preferably coated in a multi-step process, which comprises providing a stent and initially spraying the stent with a polymeric material to coat the struts. Though the steps may be reversed it is preferable to follow the spraying step with the interior coating step. In particular, the stent is placed into a hollow mold to retain the stent shape as the internal diameter of the stent is coated with the polymeric material to form a non-porous cover 200. An alternative cover could be porous for breathability or selective

leaching. The cover 100 can be provided in sheets or additional spray applications, however, the preferred embodiment is thin sheets. Sheets are generally preferred to facilitate the proper orientation of the polymer side chains to ensure that the desired moiety (e.g., hydrophilic and/or hydrophobic) is facing the lumen. Once the layer of polymer is introduced into the inner diameter of the stent, an application device such as a balloon or other device in which temperature can be regulated is implanted to sandwich the layer of polymer between the stent inner diameter and the balloon. The balloon is expanded and heated to a temperature of about between 200° and 400° F to anneal the polymer to the stent. Preferred polymers such as various designer polyurethanes (e.g., Cronoflex® manufactured by Cardiotech International) are suitable for such applications but other polymers are acceptable. Degree of conformity may depend on the compliance of the balloon as well as the presence or absence of a collar about the external surface of the stent. The collar may have ribs complementary to the stent interstices or alternatively recessed wells to facilitate the extent of super compliance of the cover.

Additionally, the same methods may be employed to cover and coat portions of the stent rather than the complete stent. In particular, smaller pieces of covering material may be applied to the distal and proximal ends of the stent to prevent excessive granulation material. Such stents would be valuable in cases such as photodynamic therapy and lung transplants where bare metal stents are generally employed.

The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as

illustrative, and not restrictive. The scope of the invention is, therefore, indicated by the appended claims, rather than by the foregoing description. All changes, which come within the meaning and range of equivalency of the claims, are to be embraced within their scope.